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Concept of the electron injector for LHeC test facility

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Outline

- Injector specification
- Possible electron sources for the LHeC TF injector
- General layout of the ERL TF injector
- Injector components
  - Electron sources. Photocathodes
  - Photocathode gun
  - Beam acceleration and manipulation
  - Beam transportation and injection into the ERL ring
  - Laser systems for the injector
- Works to be done
- Conclusion

General injector parameters

- Major design goals
  - Provide beams to the test facility
  - Test critical technologies required for LHeC
- Provided specifications
  - Bunch charge 320 pC
  - RMS bunch length <3 mm
  - RMS energy spread < 10 keV
  - Normalised RMS beam emittance < 25 π·mm·mrad*
  - Bunch repetition rate 40.08 MHz (801.6/20)
  - Initially proposed beam energy – 5 MeV*
  - Bunch time structure – regular with a gap for cleaning of traped ions in the ERL ring
- Derived specifications
  - Maximum average beam current – 12.8 mA

*-needs to be specified

Thermionic guns

- Grid modulated DC thermionic guns
  - Used in FEL-s (ELBE, FELIX, FHI)
  - Well established mature technology
  - Low cathode field
  - High emittance
  - Does not allow for generation of polarised electrons
  - Potentially able to generate high current
- Grid modulated RF thermionic guns
  - Developed for BINP ERL
  - High emittance
  - Potentially able to generate high current
  - Does not allow for generation of polarised electrons

NCRF photocathode guns

- S- and L- band guns
  - Used for high brightness injectors for FEL (FLASH,LCLS)
  - High cathode field
  - Pulsed operational mode (at a reasonable RF power)
  - Pure vacuum condition
  - Does not allow for generation of polarised electrons
- VHF guns
  - Developed as injector for FEL (LBNL)
  - Potentially able to generate high current
  - Potentially able to generate polarised electrons

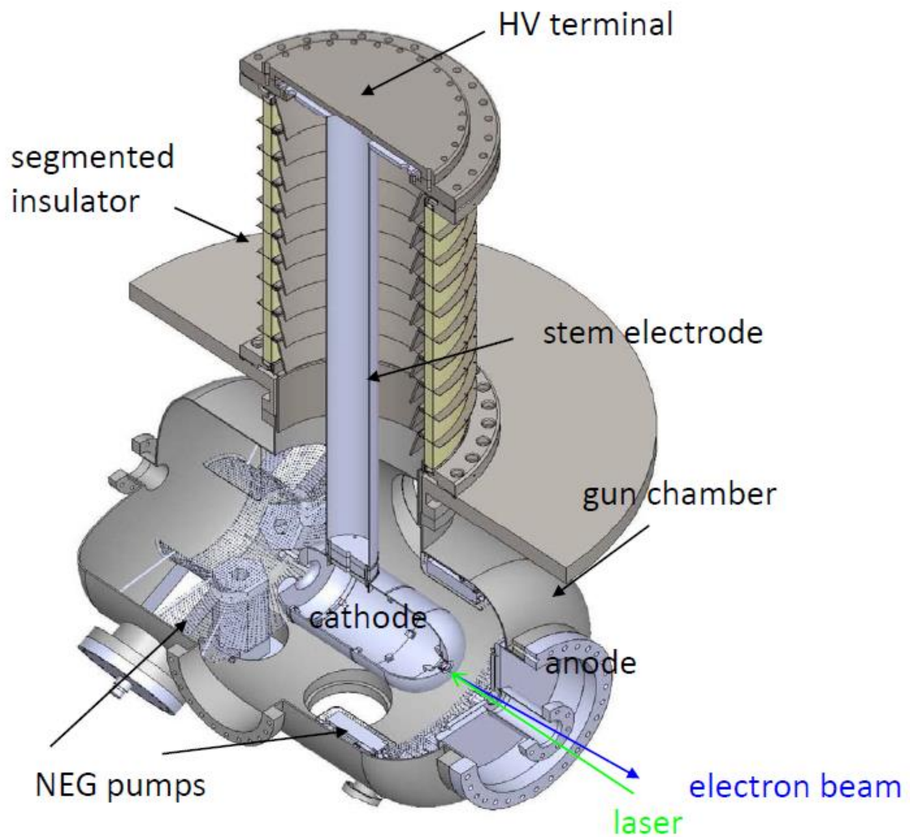
SRF photocathode guns

- S- and L- band photocathode guns
  - Developed as injector for FELs and ERLs (HZ Dresden-Rossendorf, HZ Beerlin, DESY, BNL)
  - Potentially able to generate polarised electrons
  - Potentially able to generate high current
- VHF photocathode gun
  - Developed as injectors for FELs and rings (University of Wisconsin, BNL, Naval graduate school)
  - Potentially able to generate polarised electrons
  - Potentially able to generate high current

DC photocathode gun

- Pros
  - Used and developed as ERL and FEL injectors
  - Well established mature technology
  - Experience in operation at ERLs (DL,KEK,TJNAF)
  - Possibility to deliver beams with any time structure
  - Possibility to reach extra high vacuum conditions
  - Experience in delivery of polarised electrons (TJNAF, University of Mainz, MIT, Technical University of Darmstadt, SLAC, University of Bonn, NIKHEF)
  - Demonstrated record level of average current (Cornell University)
- Cons
  - Require very accurate high voltage design
  - Low beam energy
  - Low cathode field

Photocathode gun designed at JAEA for cERL



- Maximum voltage achieved – 500 kV
- Maximum design current – 10 mA
- Photocathode – GaAs
- Photocathode preparation system (not shown) integrated with the gun
- For protection of the ceramic insulator from field emission and scattered electrons it is made segmented

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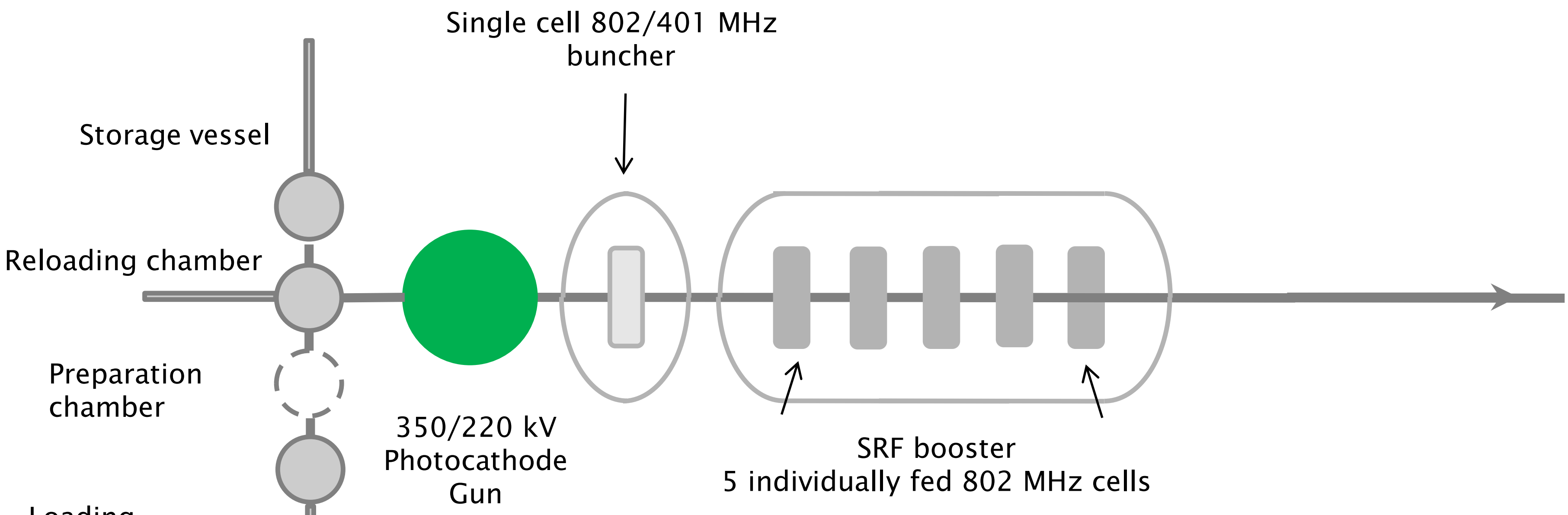
General layout of the ERL TF photoinjector



Gun voltage of 350/220 kV is chosen on the following background:

- Well established expertise of operation with 350 kV gun for Sb-based photocathodes
- Desire to reduce cathode field with a goal to decrease the dark current from GaAs type photocathodes which have low work function of 1.2 eV leads to operation at lower voltage 220kV. As requirement to emittance is modest, high cathode field is not required.

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Photocathodes for LHeC test facility

Material	Typical operational wavelength	Work function	Observed Q.E.	Laser power required for 20 mA	Observed maximum current	Observed operational lifetime
Sb-based family, unpolarised	532 nm	1.5-1.9 eV	4-5%	3.0 W**	65 mA	Days
GaAs-based family, polarised	780 nm	1.2 eV*	0.1-1.0%	20.4***	5-6 mA	Hours

Beam emittance is defined as

$$\epsilon_n = \sigma_{\perp}\sqrt{\frac{2E_{kin}}{3mc^2}} = 1 \cdot 10^{-3}\sigma_{\perp}$$

where

$$E_{kin} = \hbar\omega - \varphi = 0.83 \text{ eV}$$

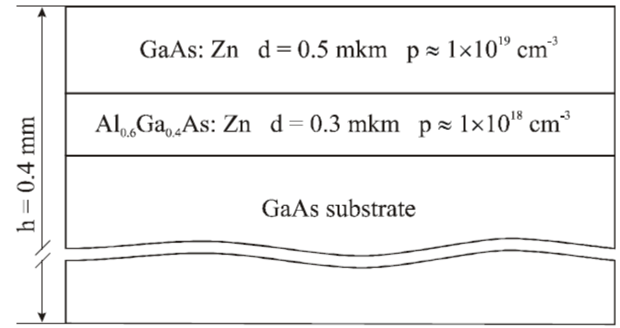
$$\sigma_{\perp} = \frac{1}{2}\sqrt{\frac{q}{\pi\varepsilon_o\mathcal{E}_c}} = 0.76\,mm$$

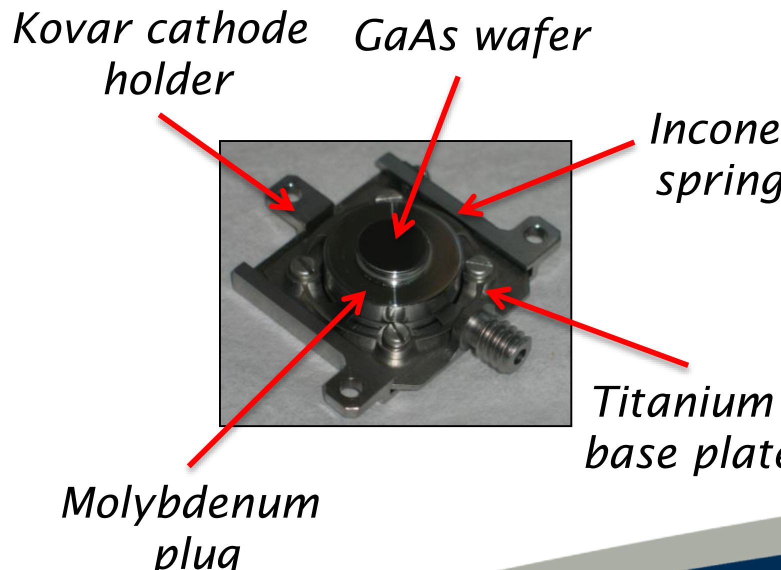
Photoinjector operation scenarios

- Photocathodes have limited lifetime and need to be replaced
- Unpolarised regime
  - Stock of photocathodes are prepared off site and brought to the photoinjector in the transport vessel
  - Photocathode are reloaded to the storage vessel
  - Photocathodes one by one are transferred to the gun and operated until their QE drops to certain level
  - When last photocathode is loaded to the gun stock renewed
- Polarised regime
  - Stock is activated on site and stored into storage vessel

Electron sources. Photocathodes

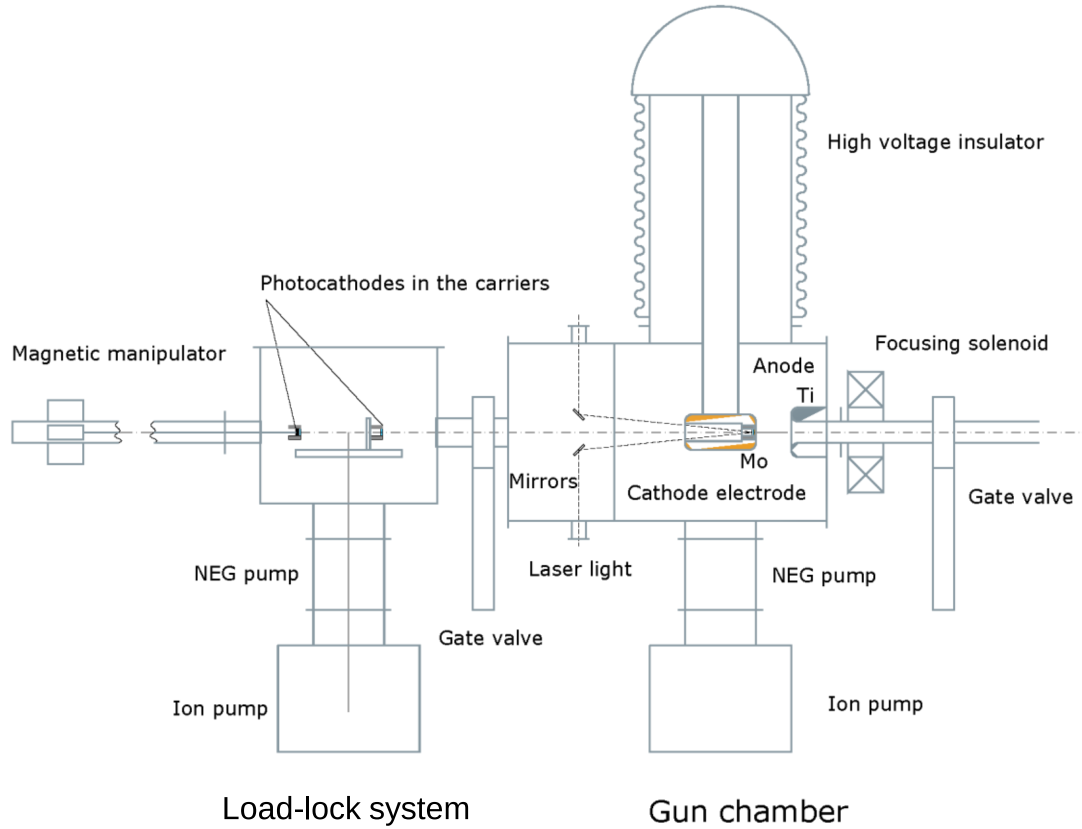
GaAs photocathode and photocathode preparation facility designed for 4GLS ERL





Example of the photocathode gun.

Maximum gun voltage, KV	400
Operational voltage, kV	350/220
Average current, mA	12.8 mA
Photocathode	Cs_3Sb/GaAs
Photocathode illumination	Backward
Photocathode substrate	Sapphire
Gun HV power supply	Integrated mono-block (not shown)
Gun insulator	Al_2O_3 segmented shielded



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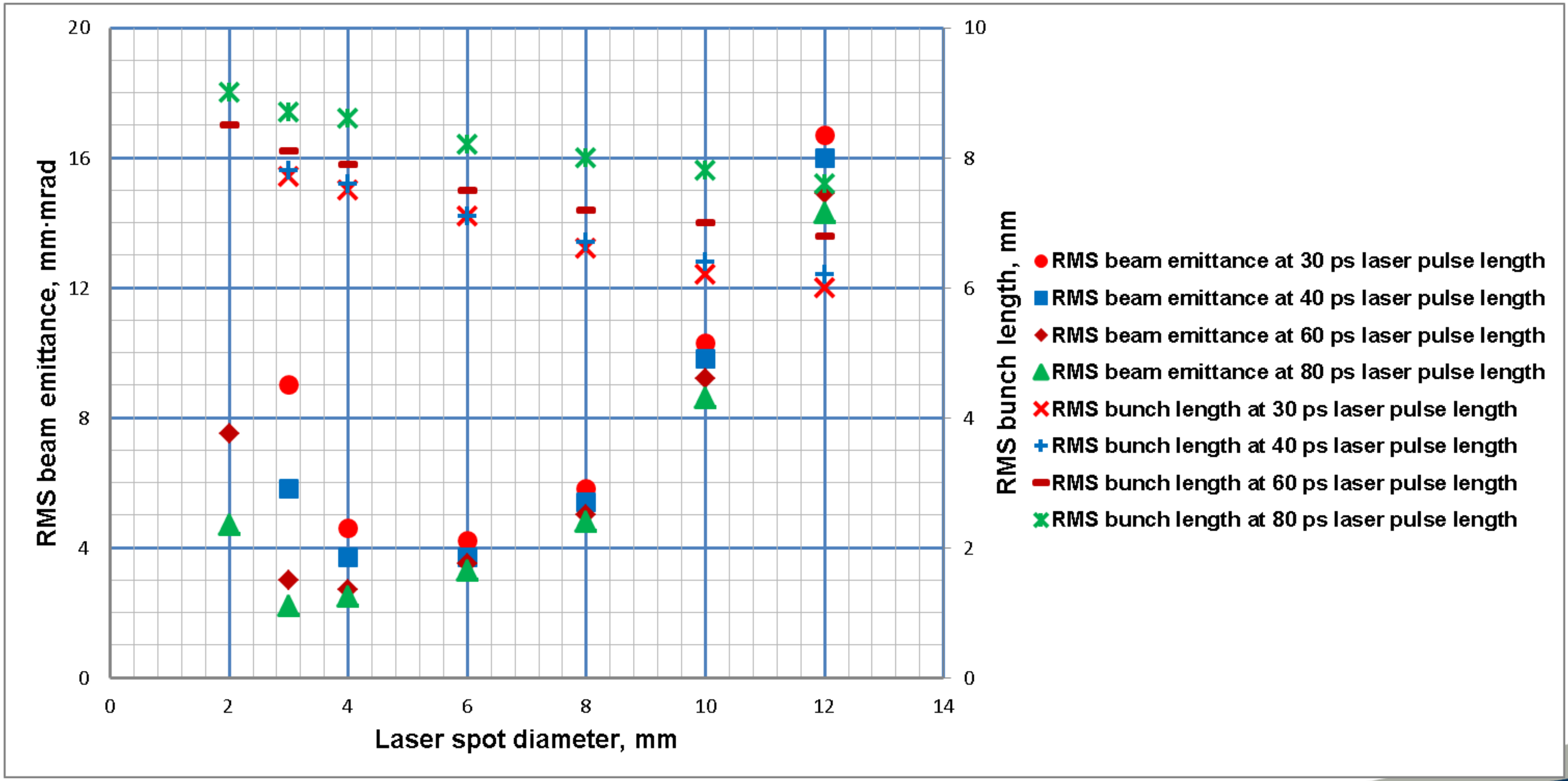
Gun operational voltage and cathode field

- High cathode operational field:
  - Allows for generation of the beams with low emittance
  - Increase field emission
  - Generates dark current and halo in unpolarised electron sources
  - Dissolves polarisation in polarised sources
- High gun voltage
  - Preserves low beam emittance
  - Impedes spin manipulation

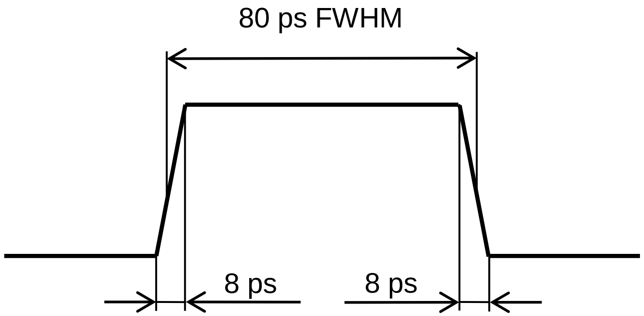
Gun emittance optimisation of a 350 kV DC photocathode gun for a bunch charge of 320 pC



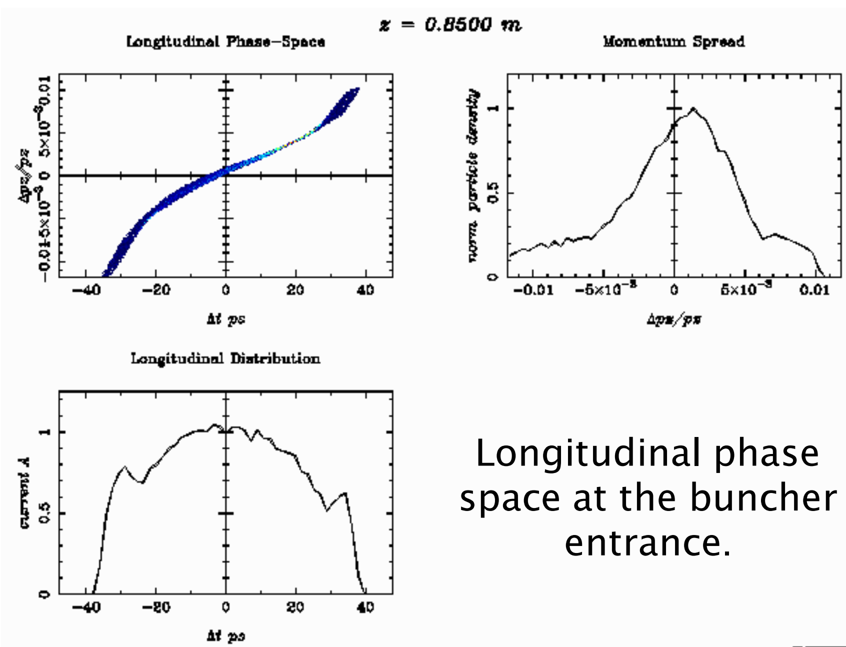
Buncher and booster

- Buncher
  - Velocity modulation of the beam requires a voltage of about 1 MV
  - Frequency is defined by the bunch length at the booster and for 8 mm should be less than 830 MHz. Main harmonic is acceptable for 320 pC
  - Gap should be as short as possible to prevent essential energy sag in the buncher
- Booster
  - Accelerate the beam to 5 MV
  - It requires RF power (CW) 60 kW
  - Number of cells 4-5 is defined by power distribution – first two cavities far fom crest
  - Individual control and coupling for at least first two cells

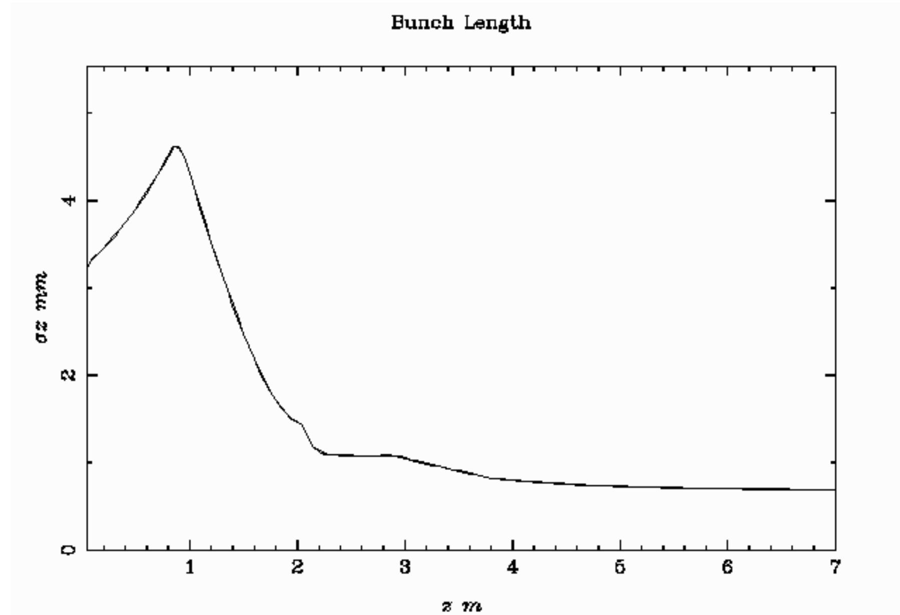
Beam manipulation. Longitudinal beam dynamics in ERL injector



Laser pulse



Longitudinal phase space at the buncher entrance.



Example of bunch length evolution along the injector beamline

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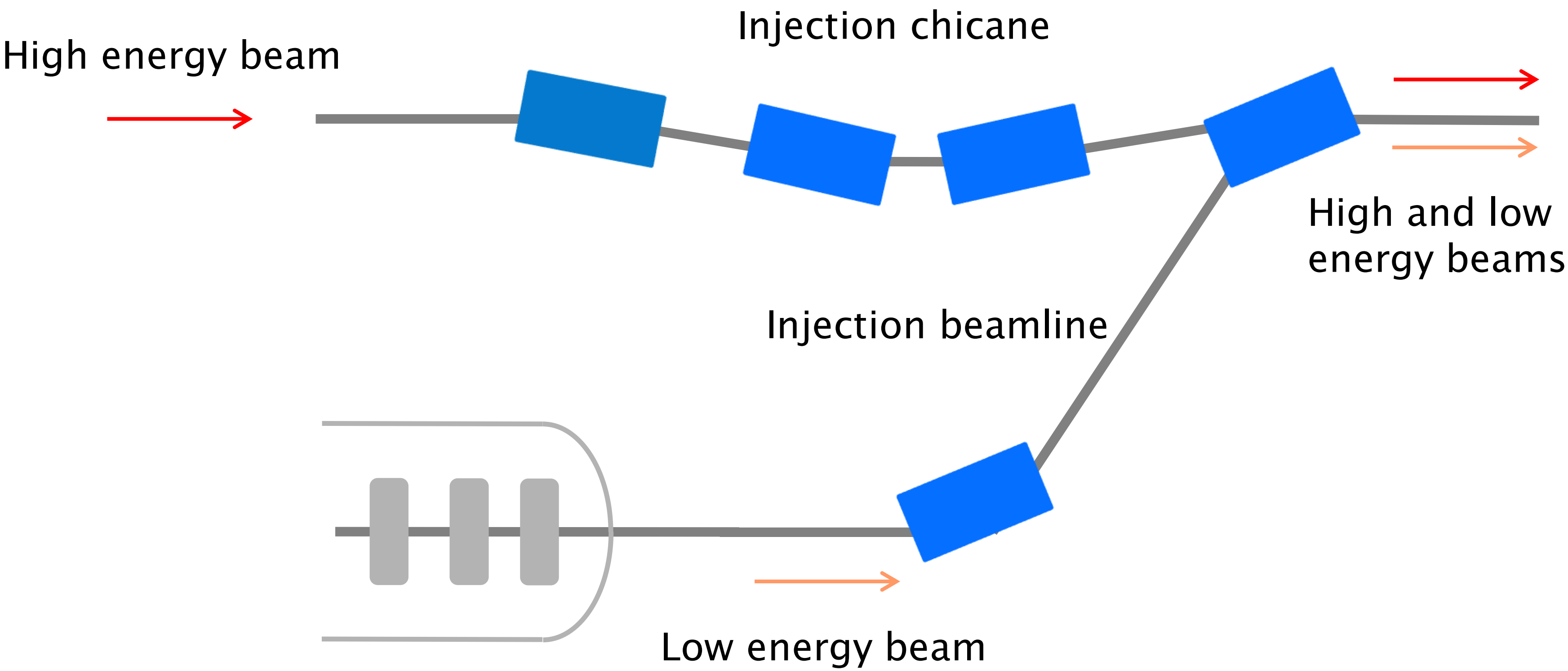
Typical ERL injection scheme



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Laser system specification for 20 mA photoinjector.

Lase wavelength, nm	532 (unpolarised mode)	780(polarised mode)
Laser pulse repetition rate, MHz	40.1	40.1
Energy in the single pulse at photocathode Qe=1%, nJ	75*	
Average laser power at photocathode Qe=1%, W	3.0*	
Energy in the single pulse at photocathode Qe=0.1%, nJ		510
Average laser power at photocathode Qe=0.1%, W		20.4
Lase pulse duration, ps FWHM	80*	80*
Lase pulse rise time, ps	8*	8*
Lase pulse fall time, ps	8*	8*
Spot diameter on the photocathode surface, mm	4*	4*
Laser spot shape on the photocathode surface	Flat top	Flat top

*-at photocathode surface

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To do:

- Optimisation of the DC gun – conceptual design, electrode system, beam dynamics, photocathode cooling
- Conceptual design of the photocathode transport system for Sb and GaAs based options
- Selection of the buncher frequency and preliminary buncher design
- Conceptual design of the booster – number of cells, gradients etc
- Optimisation of the beam transport through the booster at the proposed injection energy
- Selection of the injection scheme
- S2E beam dynamics simulation and optimisation of the injection energy if necessary

Conclusion

- It is possible to build a 5 MV injector of unpolarised electrons for the LHeC tets facility
  - Proposed scheme of the LheC TF injector based on 350/220 kV DC photocathode gun
  - Proposed photocathode material – Sb based photocathode as unpolarised source and GaAs based wafers as a source of polarised electrons.
  - The photocathode gun design should allow for operating with both type of photocathodes
  - Proposed scheme of the beam formation based on 802/401 MHz buncher and 4 cells 802 MHz booster
  - Proposed beam injection scheme but details need to be specified